



NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

Know the Earth... Show the Way... Understand the World

WGS 84 and the Web Mercator Projection

NGA Office of Geomatics

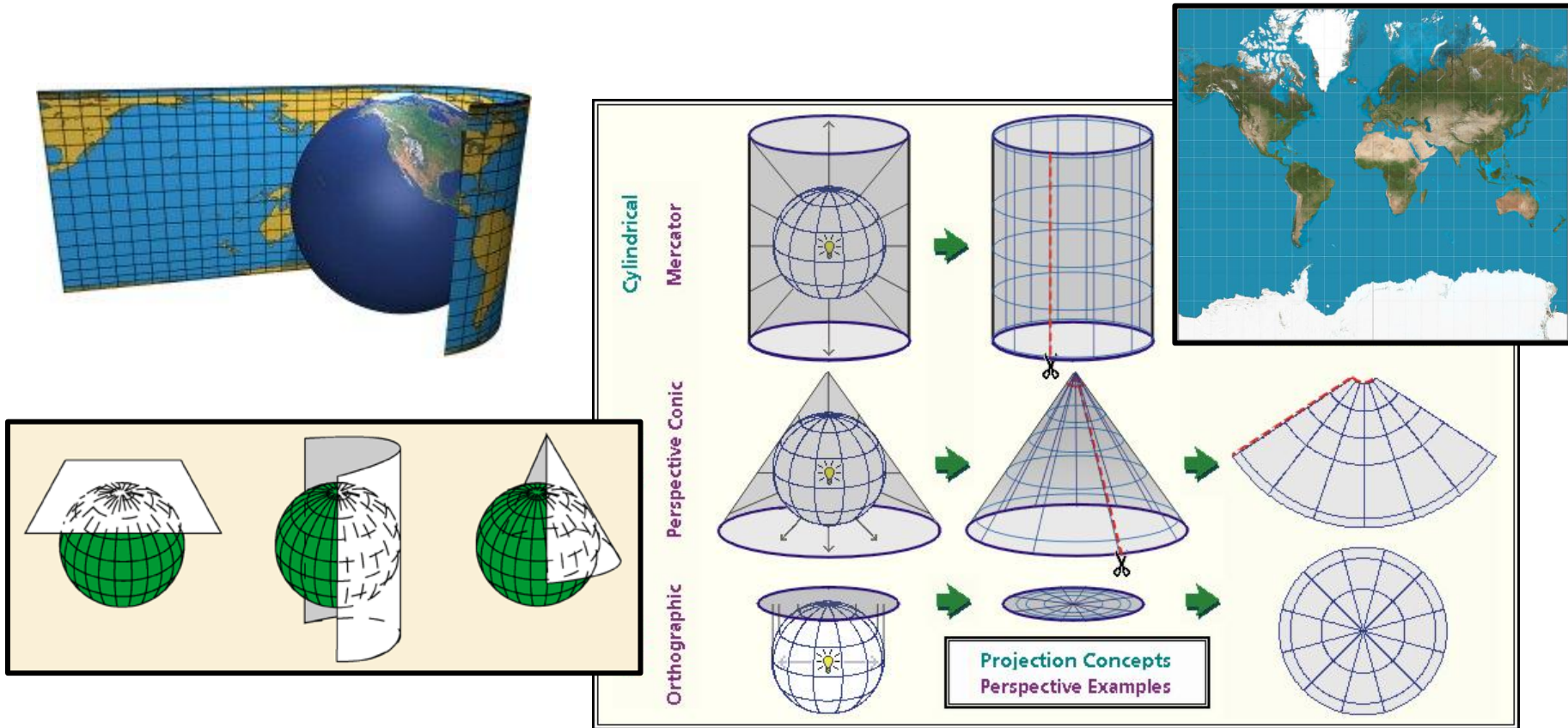
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Map Projections are a Distortion of the Truth



They attempt to 'unwrap' and 'flatten' our three dimensional world into a two dimensional map



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Nearly all of NGA's products are produced on four projections

- Mercator – most hydrographic products
- Lambert Conformal Conic – most aeronautical products
- Transverse Mercator – most topographic products
- Polar Stereographic – products near either pole

WGS 84 ellipsoid based, maintain Conformal property

Rigorous definitions, specifications, and standards exist for creation, exploitation, sharing within NSG of these product types



Let's look at two different Map Projections

WGS 84 Ellipsoid based Mercator

- Defined by WGS 84 ellipsoid, semi-major axis, eccentricity
- Ellipsoid model and math
- Converts Latitude and Longitude into a Cartesian Coordinate System (X, Y) or (Easting, Northing)
- Conformal
- Available for use in NSG systems, incorporated into GIS software
- EPSG 3395

Spherical based Web Mercator

- Sphere radius *usually* picked as WGS 84 semi-major axis
- Spherical model and math
- Converts Latitude and Longitude into a Cartesian Coordinate System (X, Y) or (Easting, Northing)
- Non-conformal
- Attributed to Google ~1995, numerous internet web mapping applications, incorporated into GIS software
- “WGS 84 web Mercator”, “WGS 1984 Web Mercator (Auxiliary Sphere)” and EPSG 3857

*European Petroleum Survey Group - EPSG

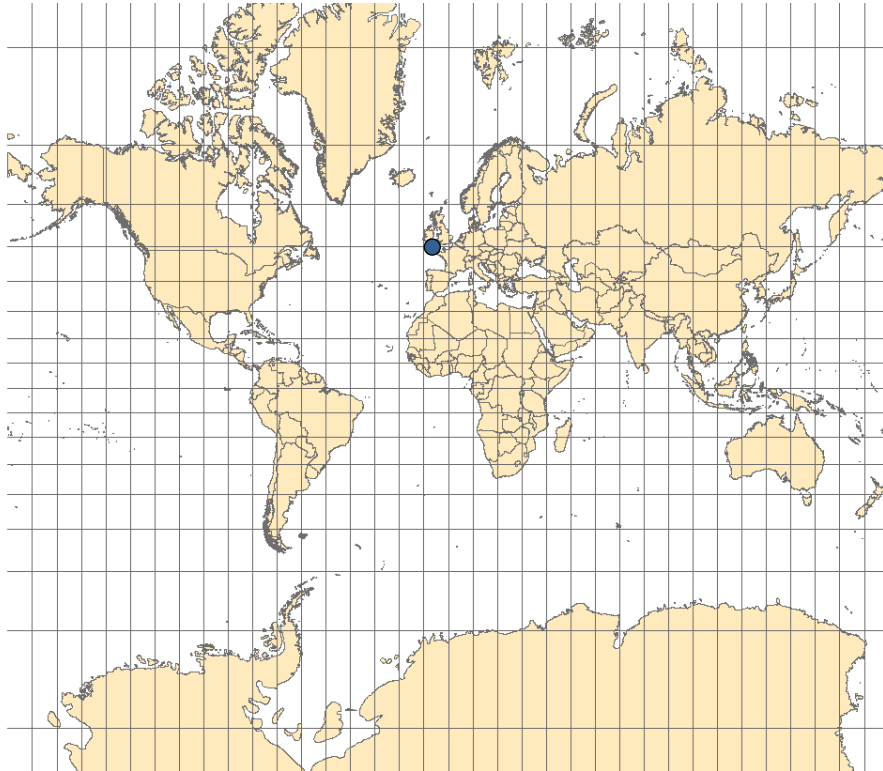


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Visually they look the same, but...

WGS 84 Ellipsoid based Mercator



Spherical based Web Mercator



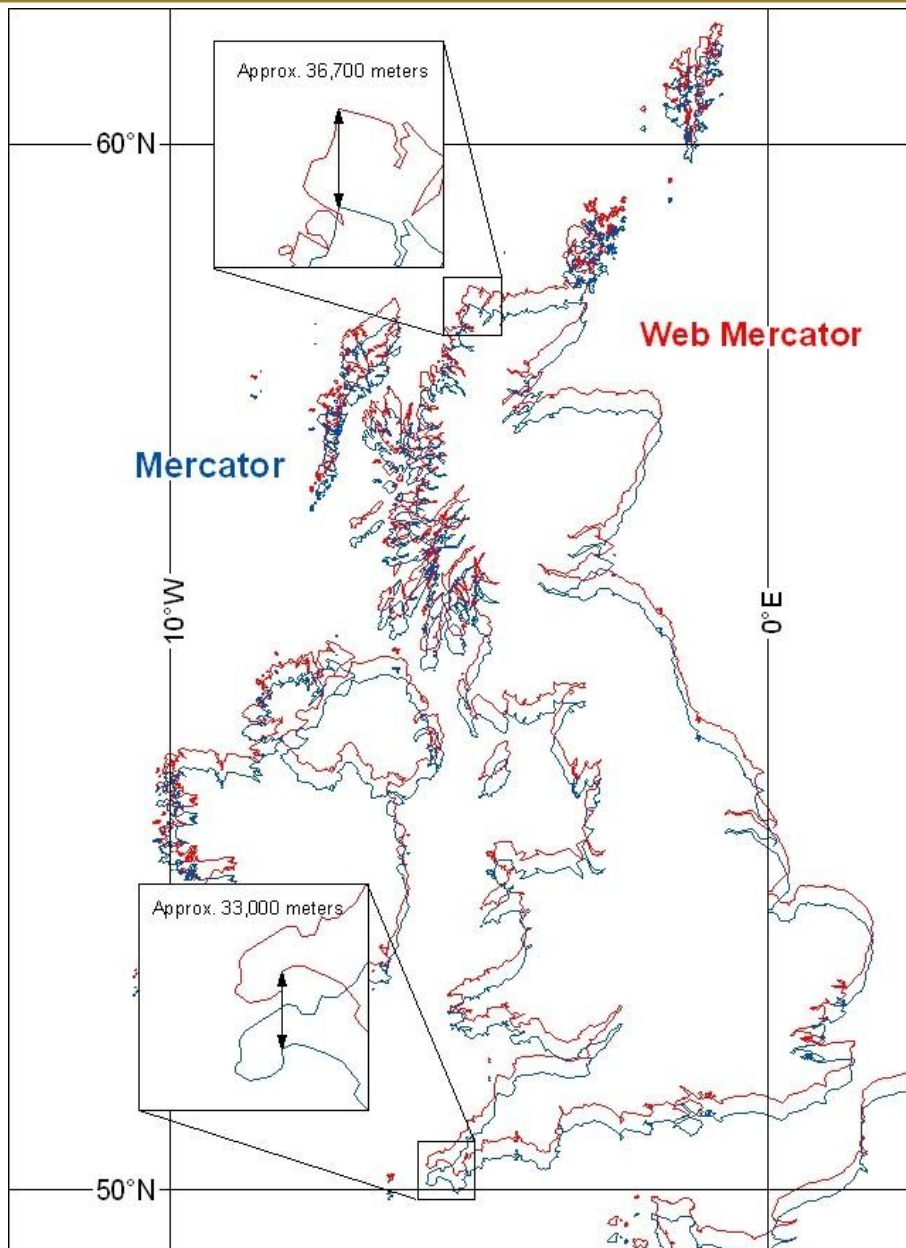


...in Reality, they are quite different

WGS 84 Ellipsoid Mercator in **Blue**
Spherical Web Mercator in **Red**
WGS 84 graticule in Black

The two insets depict

- the spherical northing shift from the ellipsoid northing
- the increasing spherical shift from the ellipsoid
 - 33.0 km at 50°
 - 36.7 km at 58°





It's not the Data, its the Math

WGS 84 Ellipsoid based Mercator Coordinate Conversion

$$x = \text{Easting} = a\lambda$$

$$y = \text{Northing} = a \ln \left[\tan \left(\frac{\pi}{4} + \frac{\phi}{2} \right) \left(\frac{1 - e \sin \phi}{1 + e \sin \phi} \right)^{\frac{e}{2}} \right]$$

$$= a \tanh^{-1}(\sin \phi) - ae \tanh^{-1}(e \sin \phi)$$

λ = longitude in radians

ϕ = latitude in radians

a = ellipsoid semimajor axis

e = ellipsoid eccentricity

Spherical based Web Mercator Coordinate Conversion

$$x = \text{Easting} = a\lambda$$

$$y = \text{Northing} = a \ln \left[\tan \left(\frac{\pi}{4} + \frac{\phi}{2} \right) \right]$$

$$= a \tanh^{-1}(\sin \phi)$$

λ = longitude in radians

ϕ = latitude in radians

a = spheroid radius

The **Easting** is the same for both since we are dealing with an *ellipsoid of revolution* and a *sphere of revolution* about the same (polar) axis.

The **Northing** is different to account for the oblate shape of the ellipsoid. The ellipsoid has a 'scaling' factor.

Since Math is HARD, lets look at it visually again...

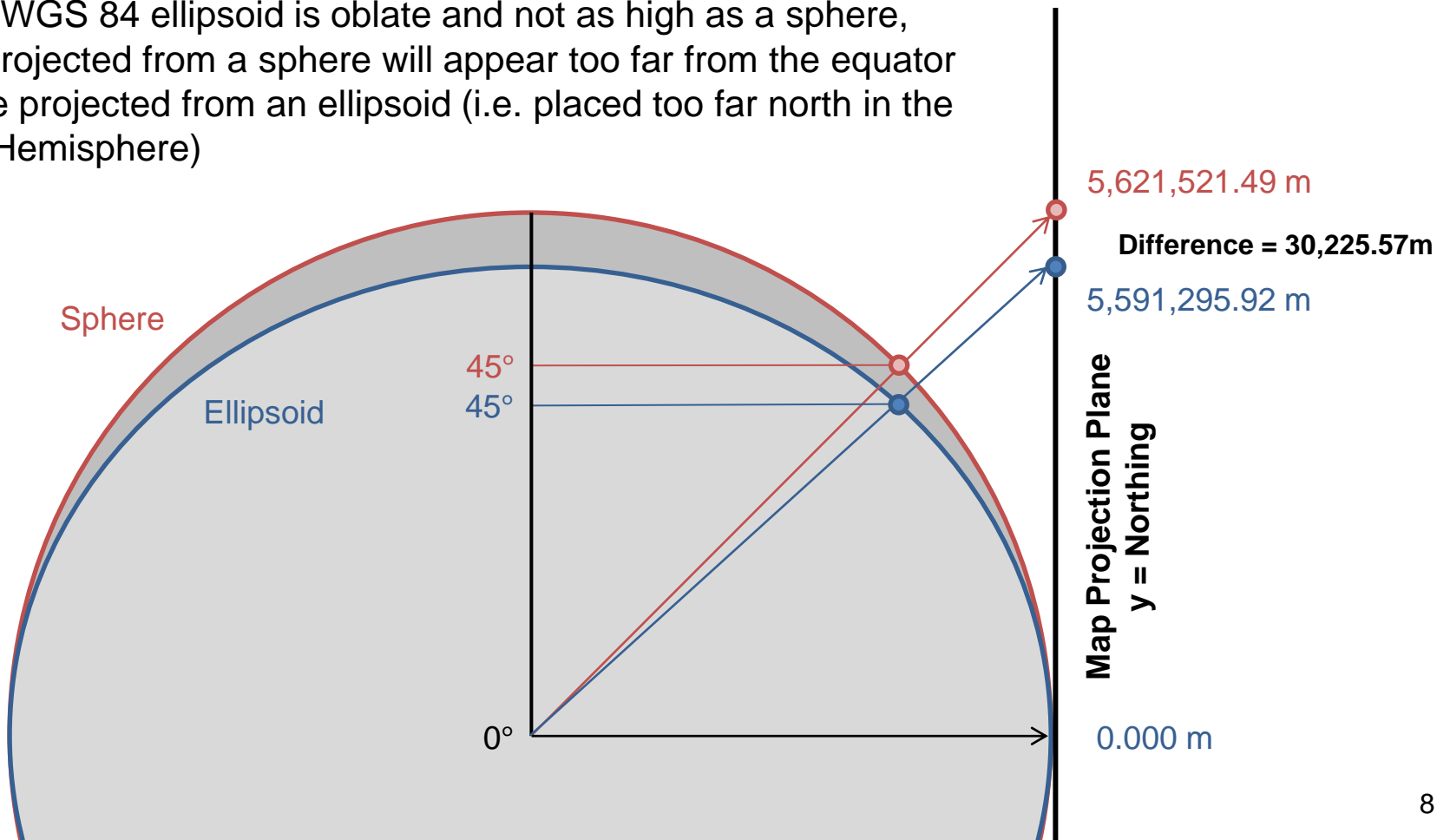


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Simplified Conceptual View of a Latitude to Northing Coordinate Conversion for a Map Projection

Since the WGS 84 ellipsoid is oblate and not as high as a sphere, features projected from a sphere will appear too far from the equator than those projected from an ellipsoid (i.e. placed too far north in the Northern Hemisphere)

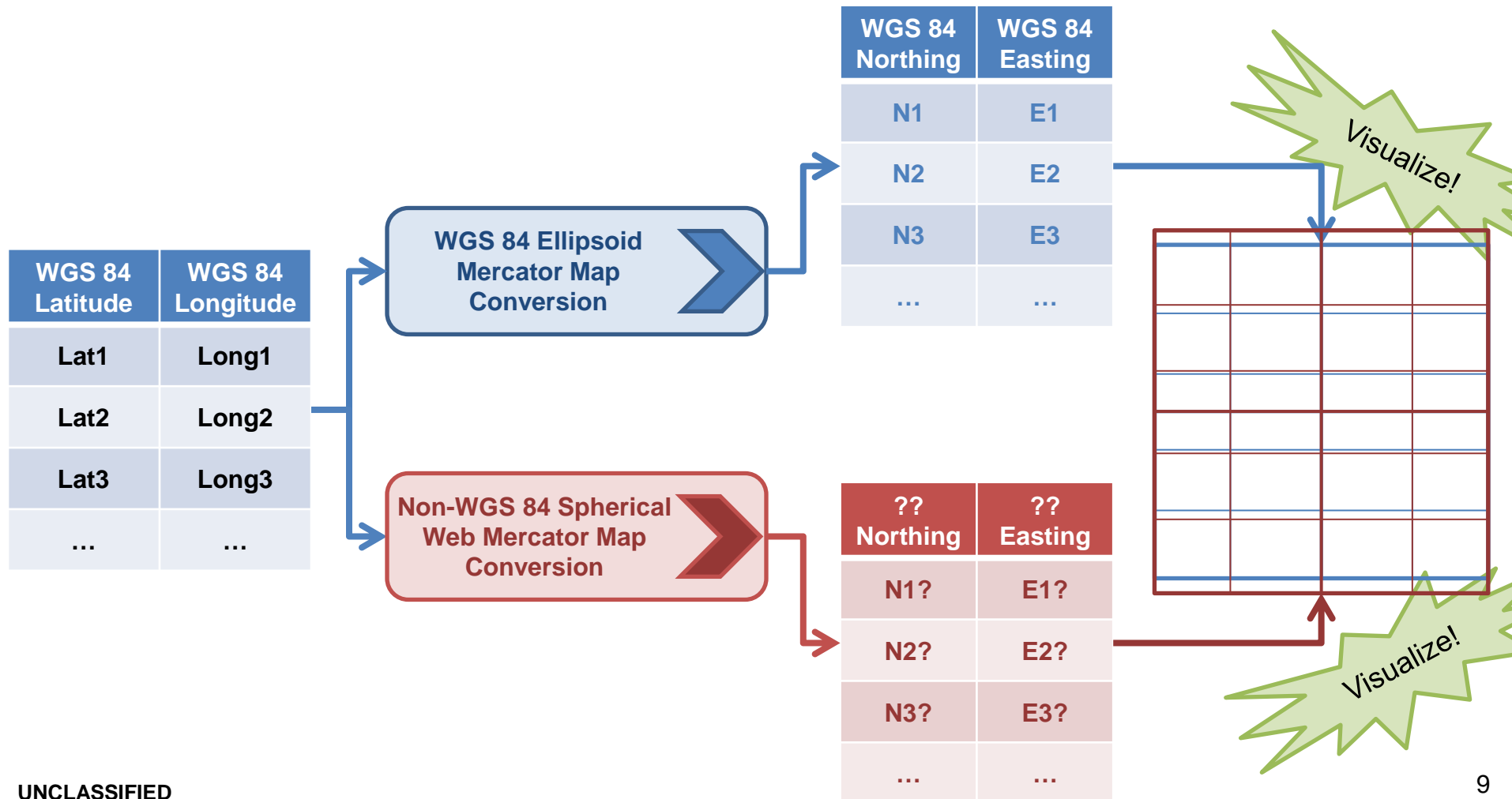




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The Coordinate Conversion Process

From Latitude and Longitude to Northing and Easting





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Ellipsoid and Spherical Northings for Selected Latitudes

	WGS 84 Latitude Deg Min Sec			Ellipsoid WGS 84 Mercator Northing (m)	Spherical Web Mercator Northing (m)	Absolute Projection Difference (m)
Point 1.0	10	00	0.000	1,111,475.10	1,118,889.97	7,414.87
Point 1.1	10	00	1.000	1,111,506.30	1,118,921.37	7,415.08
Point 2.0	20	00	0.000	2,258,423.65	2,273,030.93	14,607.28
Point 2.1	20	00	1.000	2,258,456.36	2,273,063.83	14,607.47
Point 3.0	30	00	0.000	3,482,189.09	3,503,549.84	21,360.76
Point 3.1	30	00	1.000	3,482,224.61	3,503,585.55	21,360.94
Point 4.0	40	00	0.000	4,838,471.40	4,865,942.28	27,470.88
Point 4.1	40	00	1.000	4,838,511.61	4,865,982.65	27,471.04
Point 5.0	50	00	0.000	6,413,524.59	6,446,275.84	32,751.25
Point 5.1	50	00	1.000	6,413,572.57	6,446,323.95	32,751.38
Point 6.0	60	00	0.000	8,362,698.55	8,399,737.89	37,039.34
Point 6.1	60	00	1.000	8,362,760.29	8,399,799.73	37,039.45



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Industry Partners refer to 'Web Mercator' as 'WGS 84 Web Mercator'...

	WGS 84 Latitude			Ellipsoid WGS 84 Mercator Northing (m)	WGS 84 Web Mercator Northing (m)
	Deg	Min	Sec		
Point 1.0	10	00	0.000	1,111,475.10	1,118,889.97
Point 1.1	10	00	1.000	1,111,506.30	1,118,921.37
Point 2.0	20	00	0.000	2,258,423.65	2,273,030.93
Point 2.1	20	00	1.000	2,258,456.36	2,273,063.83
Point 3.0	30	00	0.000	3,482,189.09	3,503,549.84
Point 3.1	30	00	1.000	3,482,224.61	3,503,585.55
Point 4.0	40	00	0.000	4,838,471.40	4,865,942.28
Point 4.1	40	00	1.000	4,838,511.61	4,865,982.65
Point 5.0	50	00	0.000	6,413,524.59	6,446,275.84
Point 5.1	50	00	1.000	6,413,572.57	6,446,323.95
Point 6.0	60	00	0.000	8,362,698.55	8,399,737.89
Point 6.1	60	00	1.000	8,362,760.29	8,399,799.73

Given just the 'WGS 84 Web Mercator' Northing Coordinates, how can you tell the data is derived from a spherical map projection??

"Why doesn't that NGA data fit with the WGS 84 Web Mercator data I got from industry partners and all those internet web sites?? Guess NGA got it wrong again..."



What does this mean?

Why should we care?

- The NSG (content, systems)
 - WGS 84 ellipsoid based
 - Already uses an ellipsoid based Mercator projection
- Web Mercator
 - Is not WGS 84 compliant – uses spherical mathematics, not conformal, etc
 - Does not 'solve' a map projection problem
- NGA is in discussion with multiple vendors to buy commodity content, provide cloud storage, produce APIs, Apps, Plugins. However, a lot of content, storage, apps are spheroid based Web Mercator.
- NSG personnel (acquisition, contracting, analysts, targeteers, etc.) need to understand the inherent dangers of acquiring, using, exploiting, visualizing, transmitting content in the non-WGS 84 spherical Web Mercator.



Recommendations listed in NGA.SIG.0011_1.0.0_WEBMERC

- “NGA does not endorse nor does NGA support the spherical based Web Mercator map projection (and variant namings such as WGS 84 Web Mercator) for the acquisition, visualization, exploitation, and exchange of any GEOINT data for the NSG.”
- “Any data in the spherical based Web Mercator map projection must be converted to WGS 84 ellipsoid latitude and longitude or to WGS 84 ellipsoid Mercator plane coordinates before they are used, visualized, exploited, and exchanged for the NSG. This requires knowledge of the original datum information for the data in the Web Mercator map projection.”
- “Procedures for the conversion from spherical based Web Mercator plane coordinates to WGS 84 ellipsoid based Mercator plane coordinates are specified in the Appendix of this document.”



Other Recommendations **(in terms of EPSG* codes)**

- Use EPSG 3395
 - WGS 84 World Mercator projected Coordinate Reference System
 - <http://www.opengis.net/def/crs/EPSG/0/3395>
- Do not use EPSG 3857 Popular Visualisation Pseudo Mercator CRS
 - aka Web Mercator, WGS 84 Web Mercator, etc.
 - Convert (reproject) any EPSG 3857 data into EPSG 3395

*European Petroleum Survey Group
Visualisation = UK English spelling



NGA Office of Geomatics Contact Information

- Phone
 - Commercial Phone: (314) 676-9123
 - DSN: 846-9123
- E-mail
 - UNCLAS: wgs84@nga.mil
 - SIPRNET: wgs84@nga.smil.mil
 - JWICS: wgs84@nga.ic.gov



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